Materials for Devices: Problem Set 2

5. Consider a ferroelectric material subject to an applied electric field of magnitude E. The free energy of the system is given by:

$$\mathcal{F}(P,T) = a(T - T_c)P^2 + \frac{b}{2}P^4 - EP,$$

where P is the polarisation, T the temperature, and a, b, and T_c are positive scalar parameters.

   (i) Find the minimisation condition for the free energy with respect to the polarisation. Hence, argue that $P = 0$ is not a possible state for the system.

   (ii) Calculate the zero-field electric susceptibility of the system:

$$\chi = \frac{1}{\varepsilon_0} \left.\frac{\partial P}{\partial E}\right|_{E=0}.$$

   (iii) Sketch χ as a function of temperature and discuss what happens near T_c.

6. Consider the phase diagram of $Pb(Zr_xTi_{1-x})O_3$ shown in the Figure below.

   (i) What is the Curie temperature of $PbTi_{0.4}Zr_{0.6}O_3$?

   (ii) What is the crystal structure of $PbTi_{0.4}Zr_{0.6}O_3$ at room temperature? And the crystal structure of $PbTi_{0.6}Zr_{0.4}O_3$ at room temperature?

   (iii) What conditions of polarisation would result in a specimen of $PbTi_{0.6}Zr_{0.4}O_3$ after each of the following treatments:

      (a) Strong electric field applied at 750 K, held for some hours, then switched off. Specimen cooled to 300 K.

      (b) Strong electric field applied at 620 K, held for some hours, cooled to 300 K, then field switched off.

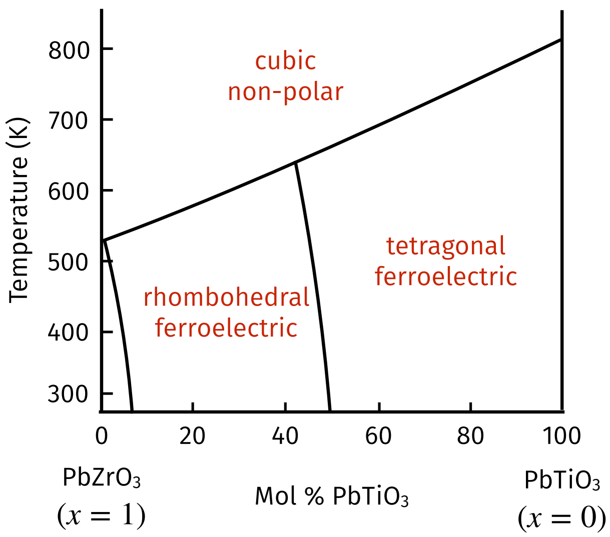
7. Consider the following data for iron and its ions:

Species	**Net magnetic moment ($\times 10^{-23}$ Am^2)**
Fe atom	2.06
Fe^{2+} cation	3.71
Fe^{3+} cation	4.64

   (i) Calculate the saturation magnetisation of elemental α-iron in the bcc structure.

   (ii) Calculate the saturation magnetisation of magnetite whose cubic cell has lattice parameter $a = 8.39$ Å.

8. A cubic transformer core is made from a nickel-iron-molybdenum ferromagnetic alloy, called supermalloy. Its power dissipation is found to be 2 W at 50 Hz. What is the energy required to switch the magnetisation direction of the transformer core?


cubic
non-polar
tetragonal
ferroelectric
rhombohedral
ferroelectric
Temperature (K)
800
700
600
500
400
300
0
20
40
60
80
100
$PbZrO_3$
$(x = 1)$
Mol % $PbTiO_3$
$PbTiO_3$
$(x = 0)$